Resource and Environmental Profile Analysis of Polyethylene Milk Bottles and Polyethylene-coated Paperboard Milk Cartons

Background

Recently, much attention has been directed at packaging by a variety of interest groups, including environmentalists, government officials, commercial and retail business managers, and legislators. This attention toward packaging has been the result of two factors:

1. An ever-decreasing landfill capacity in this country is being aggravated by an inability to site new landfills and, to a somewhat lesser extent, waste-to-energy facilities.
2. Containers and packaging account for 29.6 percent by volume of the municipal solid waste that is being landfilled, and packaging is the most visible component of solid waste to many people.

Certain packaging materials have come under particular scrutiny and have been singled out for restrictive measures such as bans or taxes.

Before decisions are made regarding individual packages or materials, a full evaluation should be made of all packaging materials and alternatives.

Objective data regarding the waste reduction, energy requirements, environmental discharges, recyclability, combustion aspects, and landfill requirements of different packaging will be crucial in determining alternative solutions to our current and future environmental problems.

Conclusions

The purpose of this study is to quantify the energy requirements and environmental emissions of both 128-ounce and 64-ounce high-density polyethylene (HDPE) milk bottles and low-density polyethylene (LDPE) paperboard milk cartons.

The following conclusions were reached regarding the total energy and environmental impacts for equivalent delivery of 1,000 gallons of milk in high-density polyethylene (HDPE) and low-density polyethylene (LDPE) coated paperboard milk containers. In this study, the term "impact" refers to the quantities of fuel and raw materials consumed and emissions released to the air, water, and land.

Franklin Associates, Ltd. Estimated in 1989 that HDPE milk bottles were being recycled at a rate less than 5 percent and paperboard milk containers at zero percent. Therefore, these conclusions are based only on zero percent recycling levels for both the HDPE and paperboard milk containers.

The study concludes that at zero percent recycling the 128-ounce HDPE milk bottle has the lowest energy requirements, least atmospheric emissions, and the lowest waterborne waste of the four containers studied. In addition, the 128-ounce HDPE milk bottle and the 128-ounce LDPE coated paperboard container have the lowest solid waste impact.

Energy

At zero percent recycling, the 128-ounce HDPE milk bottle has the lowest energy requirements of the four containers analyzed.

The next lowest energy requirements are those of the 128-ounce paperboard carton. These requirements are 16 percent greater than those of the 128-ounce HDPE bottle.

The 64-ounce paperboard carton and the 64-ounce HDPE bottle have nearly equal energy requirements and require 33 and 42 percent more energy, respectively, than the 128-ounce HDPE bottle.

Also, at zero percent recycling, the 64-ounce paperboard carton and the 64-ounce HDPE bottle require 14 and 22 percent more energy, respectively, than the 128-ounce paperboard carton.

Atmospheric Emissions

At zero percent recycling, the 128-ounce HDPE bottle has the least atmospheric emissions of the four containers. The next lowest emissions are from the 64-ounce HDPE bottle. Emissions for the 64-ounce HDPE bottle are 43 percent greater than those of the 128-ounce HDPE bottle.

Following the 64-ounce HDPE bottle is the 128-ounce paperboard carton with nearly twice the atmospheric emissions of the 128-ounce HDPE bottle and 36 percent greater emissions than the 64-ounce HDPE bottle.

The container with the greatest impact is the 64-ounce paperboard carton with:

- 2.2 times the emissions of the 128-ounce HDPE bottle;
- 1.5 times the emissions of the 64-ounce HDPE bottle; and
- 13 percent more emissions than the 128-ounce paperboard carton.

Waterborne Wastes

At zero percent recycling, waterborne wastes are lowest for the 128-ounce HDPE bottle. The 64-ounce HDPE bottle has the next lowest wastes, which are 44 percent greater than the 128-ounce HDPE bottle.

The 128-ounce paperboard carton follows next with over 3.5 times the wastes of the 128-ounce HDPE bottle and over 2.5 times the wastes of the 64-ounce HDPE bottle. The greatest waterborne wastes are contributed by the 64-ounce paperboard carton.

Solid Waste Volume

The total solid waste volumes reported in this study are the amounts of landfill space required to hold 1,000 gallon-sized HDPE bottles, 1,000 gallon-sized paperboard cartons, 2,000 half-gallon HDPE bottles, and 2,000 half-gallon paperboard cartons, along with the industrial solid wastes and secondary packaging associated with the production of each of these containers.

At zero percent recycling, the 128-ounce HDPE bottle and the 128-ounce paperboard carton have about equal solid waste volumes under landfill conditions and are the lowest of the four containers examined.

The next lowest solid waste volume is that of the 64-ounce paperboard carton. This volume is 9 to 14 percent greater than those of the 128-ounce paperboard carton and the 128-ounce HDPE bottle, respectively.

The 64-ounce HDPE bottle has the greatest solid waste volume of the four containers. Solid wastes generated by the 64-ounce HDPE bottle are:

- 37 greater than the 128-ounce HDPE bottle;

- 44 percent greater than the 128-ounce paperboard carton; and

- 26 percent greater than the 64-ounce paperboard carton.

While some degradation occurs in landfills, little data exist regarding which materials degrade and the rate of decomposition. Therefore, the degradability of both paperboard and polyethylene milk containers cannot be predicted.

As a consequence, no estimates can be made regarding the potential impact on landfill leachate or methane gas production from these containers.

Recycling

The recycling rate of HDPE bottles in 1989 was estimated at less than 5 percent. However, the infrastructure and market demand for recycled HDPE continue to rapidly grow.

While the technology for recycling paperboard exists and has been tested in pilot projects for institutional (school lunch) programs, family-size containers have not yet been targeted for recycling efforts.

For these reasons, recycling was analyzed for the HDPE containers, but not for the paperboard containers, due to a lack of available data.

As recycling rates increase, a 128-ounce HDPE container will require less energy and will contribute less solid wastes and air emissions than at zero percent recycling. This is also true for 64-ounce HDPE containers.

Combustion Impacts

On an equal weight basis, the combustion of HDPE bottles releases over twice as much energy as paperboard. This analysis, however, is based on an equivalent volume of milk delivery. By this measurement, the HDPE bottles release a similar amount of energy as the bleached paperboard cartons.

On an equivalent volume basis, HDPE will contribute less ash than paperboard. Neither the HDPE bottle nor the bleached paperboard carton will contribute significant atmospheric emissions from combustion due to their composition and the efficiency of incinerator gas scrubbers.

Methodology

A cradle-to-grave approach was used to determine the energy requirements and environmental emissions of the containers examined in this study.

This methodology quantifies energy consumption and environmental emissions at each stage of a product's life cycle, beginning at the point of raw materials extraction from the earth and proceeding through processing, manufacturing, consumer use, and final disposal, recycle, or reuse.

This analysis is intended to identify where and what wastes are generated through a cradle-to-grave study. No attempt is made to describe what the effects from these wastes may be. In other words, no attempt to determine the relative environmental effects of these pollutants, such as fish kills or groundwater contamination, as there are no accurate data available.

The term "container" is used in this study to mean the entire container delivery system, including the container itself plus all secondary packaging such as closures, labels, corrugated boxes, and delivery crates associated with the primary container.

Because these containers are examined independently, factors such as consumer preference and ease of dispensing are not considered.

Refrigeration for transport and retail storage, assumed to be equal for all four containers, was not included.

Energy use was quantified in fuel or electric energy units and converted to British thermal units (Btu) for each of the many stages, or industrial processes, required to manufacture a container.

Btu consumption was determined for six basic energy sources (natural gas, petroleum, coal, hydropower, nuclear, and wood). Energy use is considered in three areas: 1) inherent energy or energy of material resource, 2) operating the process, and 3) transporting the materials. This accounts for the use of fuels as raw materials. Thus, the energy requirements for plastics include the energy equivalent to the combustion value of the natural gas or petroleum raw material feedstocks.

Paper products do not have an energy of material source applied to their use of wood as a raw material feedstock, but all energy necessary to obtain, transport and process that fuel into a usable form is calculated.

As with energy, the environmental wastes from each step or process were determined. Government documents, as well as federal regulations, technical literature, and industry sources form the basis for these data. These wastes represent actual discharges into the environment after emissions control devices. The environmental emissions can be classified into three broad categories: solid waste, atmospheric emissions, and waterborne wastes.

These categories include not only those readily identifiable wastes associated with a specific process, but also the pollutants associated with the fuels consumed in power generation or transportation. The solid waste category includes both industrial solid waste and post-consumer solid waste.

Energy use and environmental emissions were determined for various post-consumer recycling levels for the HDPE, containers. HDPE milk containers are currently recovered and recycled in some parts of the country. The infrastructure to collect, process, and recycle HDPE is rapidly developing.

The use of zero percent to 100 percent recycling rates is not meant to portray unrealistic expectations. However, the recycling rate is used to illustrate how energy use and environmental releases change as the recycling rate increases.

The recycled polyethylene is assumed to replace virgin materials in producing new products.

An open-loop recycling system splits the requirements of physically processing the recycled material and credits the product examined in the study with an overall industry replacement of virgin material.

The full study considers both open and closed-loop recycling systems. For the purpose of this summary only open-loop recycling systems are presented because open-loop recycling mirrors the situation for each package today. Additional data on closed-loop recycling is available in the full study.

During this study, the research team determined that several pilot recycling programs had been established (in late 1990) for LDPE-coated paperboard containers.

These programs involve single-service institutional containers (e.g., for school lunch programs), which utilize the same material as the family-sized paperboard cartons examined in this study. However, these larger containers have not been targeted in these pilot programs.

With the preceding factors recognized, the energy requirements and environmental emissions for the paperboard containers analyzed in this study were calculated only at a zero percent recycling rate.

We do, however, note that the technical and economic feasibility of recycling post-consumer paperboard containers is now being demonstrated. While no conclusions can be drawn with regard to recycling potential, the zero percent rate simply reflects recycling practice at the time of this report and is not a conclusion about the recyclability of paperboard containers.

However, the post-consumer paperboard milk carton does appear to be on the threshold of recycling and may follow the development pattern of other materials recently targeted for recycling. As the recycling of paperboard milk cartons develops and data become available, the analysis of family-size cartons should be developed considering zero to 100 percent recycling.

The combustion of post-consumer packages was also included in this analysis. The U.S. EPA Characterization of Municipal Solid Waste: 1990 Update shows (after recycling) that a national average of approximately 15 percent of the municipal solid waste (MSW) stream is combusted in incinerators, with energy recovery. Thus, the post-consumer solid waste and the energies for the containers were adjusted for 15 percent combustion.

Solid waste in the form of ash resulting form combustion incineration, such as the inorganics remaining after combustion, was estimated from the ash inherent in the materials.

However, the atmospheric emissions that result from incinerator combustion of the polyethylene and bleached paperboard with municipal solid waste could not be estimated due to lack of data.

While emissions from municipal solid waste incinerators have been characterized, we have no way to attribute these emissions back to a given material. Some studies have characterized the changes in emissions of average MSW to those of MSW "spiked" with specific materials. However, these types of analyses have not been done for bleached paperboard or polyethylene.

Most atmospheric emissions from municipal solid waste incinerators are treated in the gas scrubbers used in these facilities. These atmospheric emissions are eventually disposed of in scrubber blowdown as solid waste.

Since the atmospheric emissions for paperboard and polyethylene cannot be quantified, the impact of these emissions on scrubber blowdown also cannot be determined.

The margin of error for this study is believed to be plus or minus 10 percent. Therefore, distinctions in energy use and environmental emissions will only be significant if the difference is greater than 10 percent. The nature of error in this analysis is systematic and not due to randomness. Thus, the margin of error cannot be statistically determined.

Resul t s

The results of this analysis are organized by two categories: energy requirements and environmental emissions. For both the energy and environmental results, the findings are presented on the basis of 1,000 gallons of milk delivered.

Energy Requirements

The energy requirements for HDPE and paperboard milk containers are reported in Table 1-1. They are reported for 1,000 gallons of milk at varying recycling rates for the HDPE bottles and zero percent recycling for the paperboard cartons. Figure 1-1 is a graphic illustration of the energy requirements reported in Table 1-1.

Zero Percent Recycling. Both Table 1-1 and Figure 1-1 show that at zero percent recycling, the 128-ounce HDPE bottle has the lowest total energy requirements of the four containers at 5.5 million Btu.

The 128-ounce paperboard carton has the next lowest energy requirements at 6.4 million Btu. The 64-ounce paperboard carton and he 64-ounce HDPE bottle have nearly equivalent energy requirements at 7.3 and 7.8 million Btu, respectively.

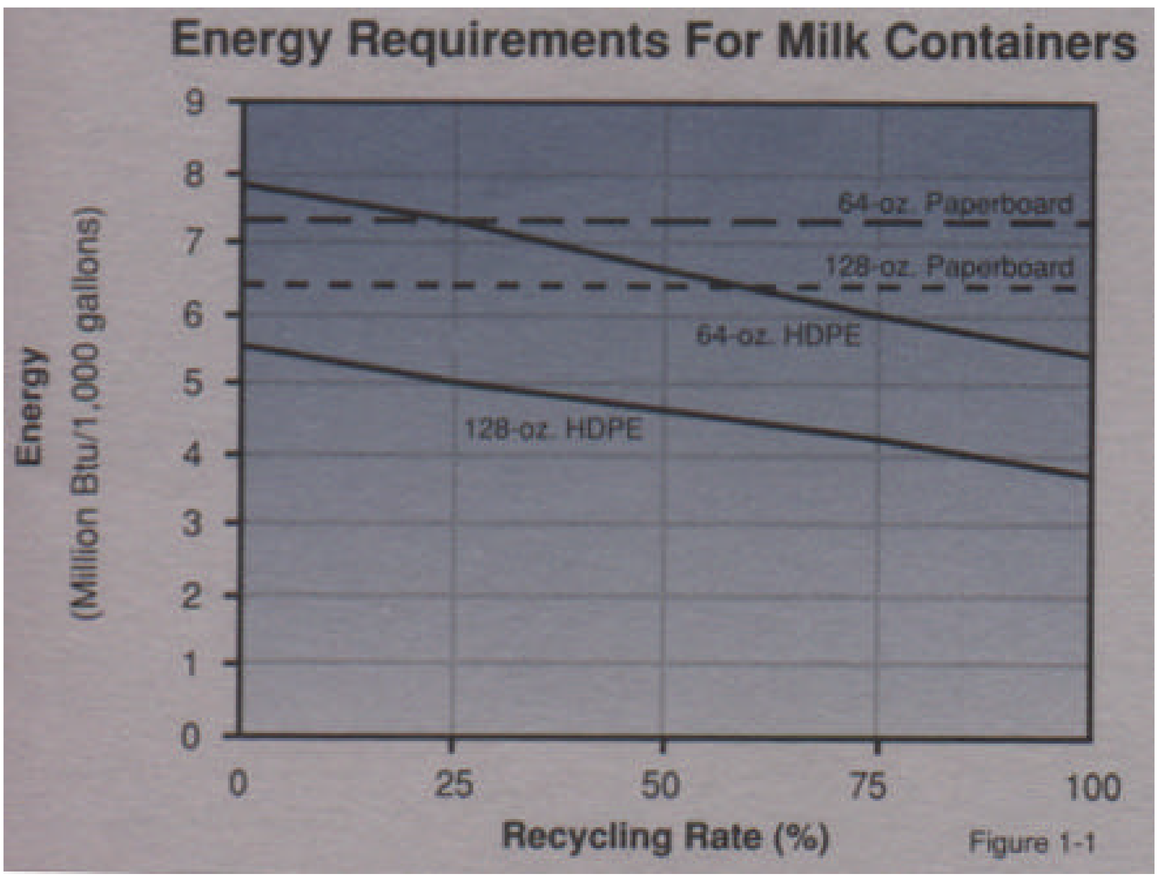

Figure 1-1

The two 64-ounce containers have the highest energy requirements of the four containers analyzed. These relationships are all expressed holding paperboard constant at zero percent recycling.

Various Recycling Rates. When open-loop recycling is considered for the HDPE bottles, the 128-ounce HDPE bottle continues to have the lowest energy requirements of the four containers at all recycling rates.

Table 1-1
ENERGY REQUIREMENTS FOR HDPE AND PAPERBOARD MILK CONTAINERS AT VARIOUS RECYCLING RATES (1)
(Million Btu's per 1,000 gallons of milk)

	Recycling Rates (2)				
	0%	25%	50%	75%	100%
128-ounce HDPE					
(1,000 containers)					
Open-loop	5.5 (3)	5.0	4.6	4.2	3.7
128-ounce paperboard					
(1,000 containers)	6.4 (4)				
64-ounce HDPE					
(2,000 containers)					
Open-loop	7.8 (3)	7.3	6.6	6.0	5.4
64-ounce paperboard	7.3 (4)				
(2,000 containers)					

Source: Franklin Associates, Ltd.

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(1) Assumes 15 percent of post-consumer solid wastes are combusted for energy recovery.

(2) Recycling is presented here at rates of 0 percent to 100 percent. The use of this range is not meant to indicate current levels of recycling or to predict future recycling rates. The range is merely a theoretical tool used to help interpolate recycling rates between the two endponits. The current recycling rate (1989) for HDPE milk bottles is estimated by Franklin Associates, Ltd. to be less than 5 percent.

(3) The inherent energy in the plastic milk bottles is 60 percent of the total energy. Not all the energy may be recovered from the of the combustion of the plastic bottles because of the change in molecular structure due to processing of fossil fuels into plastic products.

(4) Recycling is not considered for the paperboard milk carton. The inherent energy of the LDPE coating on the milk carton is 10 percent of the total milk carton energy. The process energy attributed to wood is 31 percent of the total energy of the paperboard carton.

The 128-ounce paperboard carton has the second lowest energy requirements until the open-loop recycling rate of the 64-ounce HDPE bottle reaches 83 percent. At this recycling rate, the energy requirements for the 64-ounce HDPE bottle become significantly less than those for the 128-ounce paperboard.

The 64-ounce paperboard carton and the 64-ounce HDPE bottle continue to have equal energy requirements until the recycling rate of the 64-ounce HDPE bottle is greater than 50 percent. At this point, the energy requirements of the 64-ounce HDPE bottle are significantly less than those of the 64-ounce paperboard cartons. These relationships are expressed holding paperboard constant at zero percent recycling.

Several observations about energy are important to understand:

1. The inherent energy of the HDPE bottle and of the LDPE coating on the paperboard is considered an energy "cost" to each milk container system because plastics are derived from hydrocarbon sources.

   Hydrocarbons (such as natural gas, natural gas liquids and petroleum) are principally used as fuels in the United States; therefore, when these materials are used as raw materials they are removed from our energy resource supply.

   Thus, besides process and transportation energy, systems using these materials as raw materials have an additional energy included equal to the energy equivalence of the initial fossil fuel sources. The inherent energy of the HDPE containers is about 60 percent of the total energy at zero percent recycling.

2. In contrast, because wood is not used primarily as an energy resource in the United States, no inherent energy is attributed to the use of wood as a raw material for the paperboard container. This does not mean, however, that the energy obtained from the combustion of wood-derived sources (bark, black liquor, etc.) is not included.

   On the contrary, because this analysis quantifies the total energy requirements necessary to operate a process or transport materials from all sources, wood-derived energy is handled no differently. When used for these purposes, the energy derived from wood resources for the production of paperboard containers is about 31 percent of the total energy.

Environmental Emissions

The environmental emissions for the containers are divided into three groups:

1. Solid Wastes
2. Atmospheric Emissions
3. Waterborne Wastes

These emissions are reported in Table 1-2.

Solid Wastes. The landfill volume of the solid wastes generated by the production, use, and disposal of milk containers is reported in Table 1-2 in cubic feet per 1,000 gallons of milk and includes both post-consumer and industrial solid waste.

This waste category includes only materials actually discarded into the waste stream; therefore, industrial scrap or trimmings that are currently recycled for both packaging materials are not considered waste.

Post-consumer solid waste volume was derived from weight by applying general material density factors. For industrial solid waste, a density of 50 pounds per cubic foot was used. Post-consumer solid waste is adjusted for 15 percent combustion of all materials not recycled.

Zero Percent Recycling. Table 1-2 and Figure 1-2 show that at zero percent recycling, the 128-ounce HDPE bottle and the 128-ounce paperboard carton have the lowest solid waste effect and are nearly equivalent at 9.4 and 8.9 cubic feet, respectively.

The 64-ounce paperboard container has the next lowest solid waste at 10.2 cubic feet. The 64-ounce HDPE bottle has the greatest amount of solid waste of the four containers at 12.9 cubic feet.

Various Recycling Rates. When recycling is considered for the HDPE bottles, the 128-ounce HDPE bottle and the 128-ounce paperboard carton continue to have equal solid wastes until a recycling rate of 16 percent for the HDPE bottle is reached. At this recycling rate, the 128-ounce HDPE bottle has significantly lower solid waste than the paperboard container and continues to have the lowest solid waste at all recycling rates.

Table 1-2
ENVIRONMENTAL IMPACT DATA FOR CONTAINERS
(Impacts per 1,000 gallons of milk) (1)

	Solid Waste (2) (cu. ft.)	Atmospheric Emissions (pounds)	Waterborne Wastes (pounds)
128-ounce HDPE			
(1,000 containers)			
Open-loop			
0% Recycle	9.4	10.1	0.9
25% Recycle	7.3	9.4	0.9
50% Recycle	5.1	8.7	1.0
75% Recycled	2.9	7.9	1.1
100% Recycle	0.7	7.2	1.1
128-ounce paperboard (3)			
(1,000 containers)			
0% Recycle	8.9	19.6	3.4
64-ounce HDPE			
(2,000 containers)			
Open-loop			
0% Recycle	12.9	14.4	1.3
25% Recycle	9.9	13.5	1.3
50% Recycle	6.9	12.5	1.4
75% Recycled	3.9	11.5	1.5
100% Recycle	1.0	10.5	1.6
64-ounce paperboard (3)			
(2,000 containers)			
0% Recycle	10.2	22.2	3.8

Source: Franklin Associates, Ltd.

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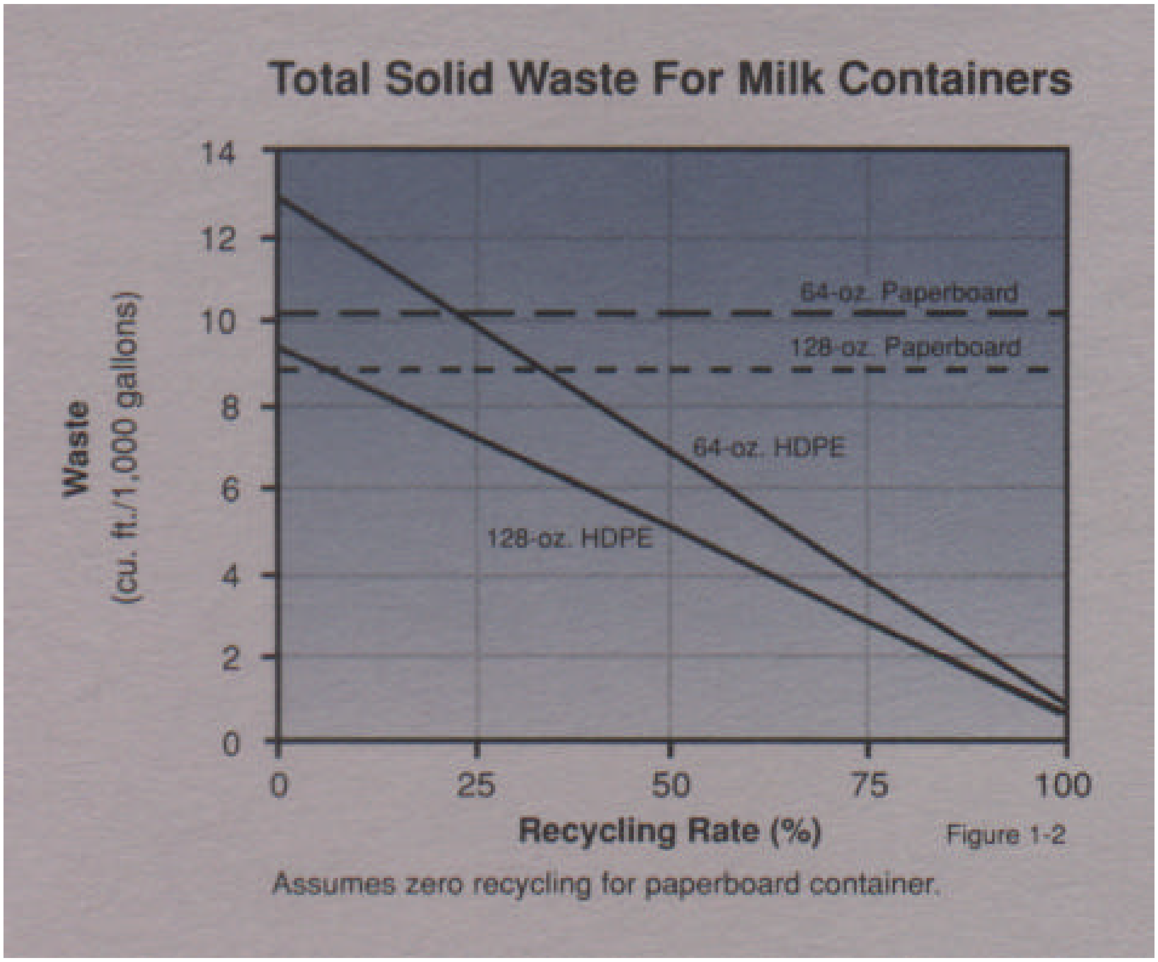
(1) Recycling is presented here at rates of 0 percent to 100 percent. The use of this range is not meant to indicate current levels of recycling or to predict future recycling rates. The range is merely a theoretical tool used to help interpolate recycling rates between the two endpoints. The current recycling rate (1989) for HDPE milk bottles is estimated to be less than 5 percent.

(2) Values represent landfill volumes in cubic feet.

(3) Recycling is not considered for the paperboard milk carton.



The 64-ounce HDPE bottle has the greatest solid waste landfill volume until a recycling rate of 15 percent is reached. At this recycling rate, it is equal to the 64-ounce paperboard container until a recycling rate of 30 percent is reached. At this rate, the 64-ounce HDPE bottle contributes less solid waste than the 64-ounce paperboard carton.

At a 26 percent recycling rate, the solid waste for the 64-ounce HDPE bottle is equal to that of the 128-ounce paperboard container. The 64-ounce HDPE bottle remains equal to the 128-ounce paperboard carton until a recycling rate of 41 percent is reached. At this point, the 64-ounce HDPE bottle contributes the second lowest solid waste of the four containers.

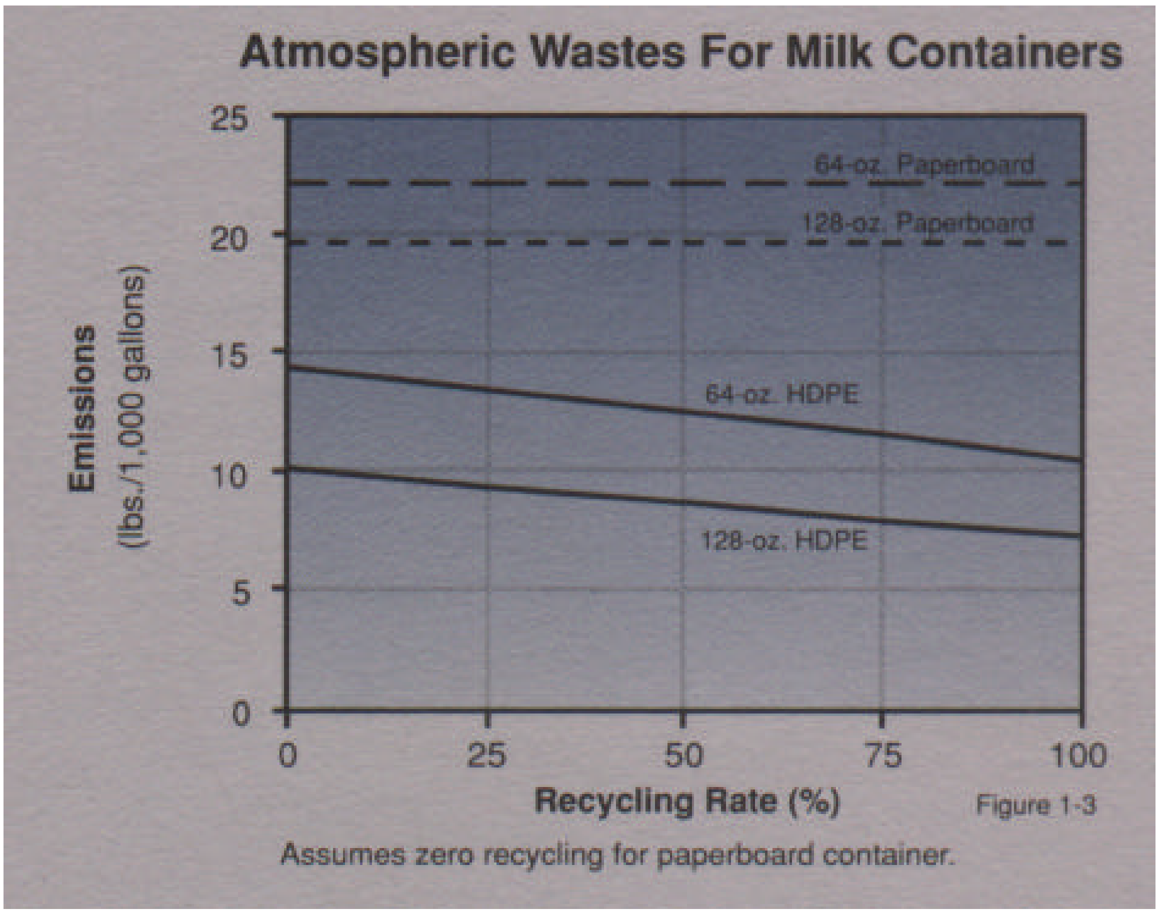
These comparisons are made with paperboard cartons at a zero percent recycling rate only. Consider that the HDPE bottle has a rigid handle, rigid bottom, and rigid spout, all of which contribute resistance to total flattening of the container, as well as to the resiliency of the material.

The pressure applied under landfill conditions by both the compactor vehicle, which may miss containers in its passes, and the weight of layers above the buried refuse is not great enough to overcome these factors and completely flatten the HDPE bottle.

On the other hand, paperboard cartons are inherently more flexible and require less pressure to be flattened. The fact that paperboard absorbs moisture in the landfill will increase the degree to which the container is flattened.

Atmospheric Emissions. Table 1-2 lists atmospheric emissions for the entire analysis of the milk containers in pounds per 1,000 gallons of milk. Figure 1-3 also illustrates these impacts for all four containers. Table 1-2 and Figure 1-3 show that at zero percent recycling, the 128-ounce HDPE bottle has the least atmospheric emissions of the four containers, with 10.1 pounds.

The container with the next lowest emissions is the 64-ounce HDPE bottle with 14.4 pounds. The 128-ounce and 64-ounce paperboard cartons follow the HDPE bottles with 19.6 and 22.2 pounds of emissions, respectively.

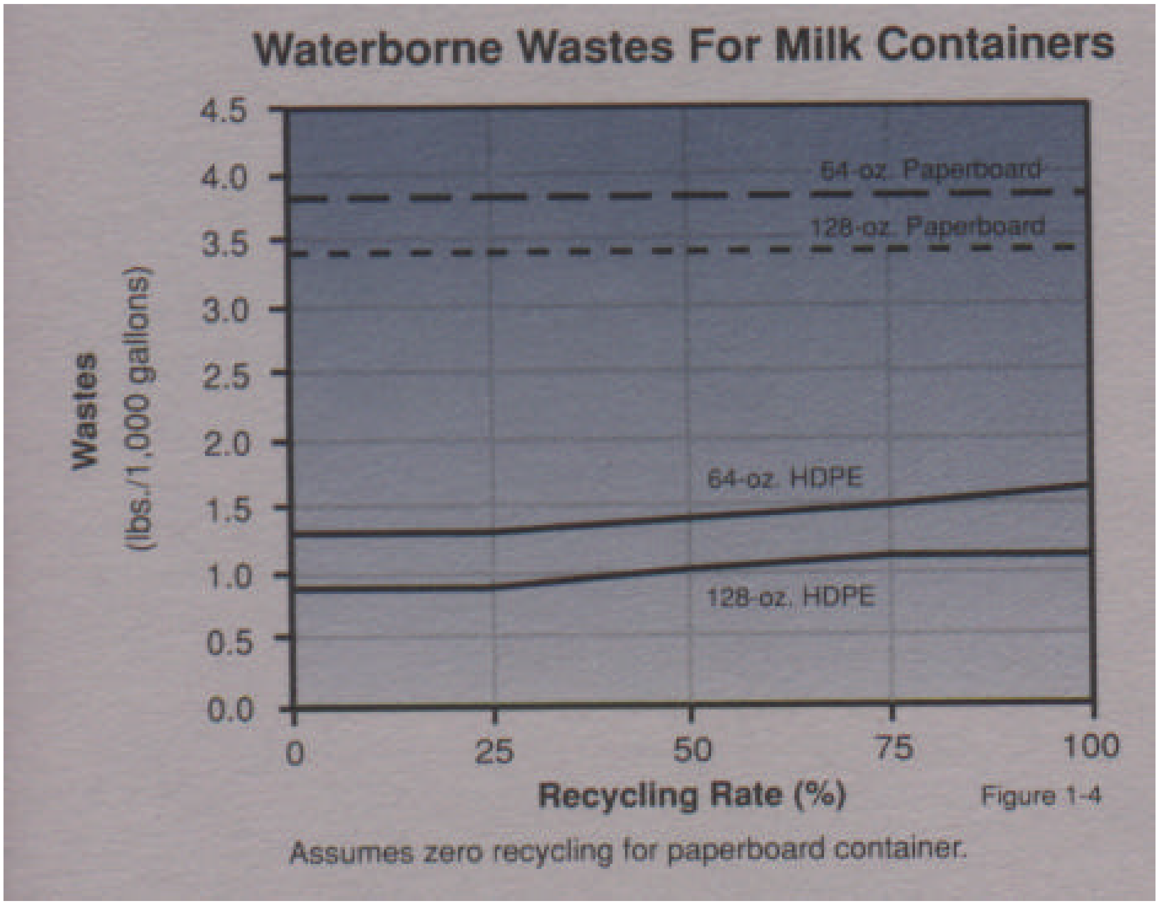


As open-loop recycling is considered for the HDPE bottles, the atmospheric emission for these containers decrease. However, the relative ranking of the four containers does not change.

Waterborne Wastes. The waterborne wastes for the delivery of 1,000 gallons of milk in this cradle-to-grave analysis are reported are reported in Table 1-2 and graphed in Figure 1-4.

Table 1-2 and Figure 1-4 show that at zero percent and at all recycling rates, the 128-ounce HDPE bottle has the lowest waterborne wastes of the four containers. The 64-

ounce HDPE bottle contributes the next lowest waterborne wastes. This is followed by the 128-ounce and 64-ounce paperboard cartons, respectively.



Summary

The research reported in this study focuses on the environmental impact of high-density polyethylene (HDPE) milk bottles and low-density polyethylene (LDPE) coated paperboard milk cartons. The study concludes that at zero percent recycling, the 128-ounce HDPE bottle has the lowest energy requirements of the four containers studied. The 128-ounce paperboard carton has the next lowest energy requirements. The 64-ounce paperboard carton and 64-ounce HDPE bottle have nearly equal energy requirements.

The 128-ounce HDPE bottle and the 128-ounce paperboard carton have the lowest solid waste effect and are nearly equal at zero percent recycling. The 64-ounce paperboard carton has the next lowest solid waste impact. The 64-ounce HDPE bottle results in the greatest amount of solid waste volume until a 15 percent recycling rate is achieved. At this recycling rate, it becomes equal to the smaller paperboard carton in terms of solid waste impact.

At zero percent recycling, the 128-ounce HDPE bottle has the least atmospheric emissions of the four containers. The container with the next lowest emissions is the 64-ounce HDPE bottle. When recycling is factored in, the rankings of the containers do not change.

At all recycling rates, the 128-ounce HDPE bottle has the lowest waterborne wastes of the four containers. The 64-ounce HDPE bottle contributes the next lowest waterborne wastes, followed by the 128-ounce and 64-ounce paperboard cartons, respectively.

Copies of the full study are available from:

The Council for Solid Waste Solutions
1275 K Street, NW, Suite 400
Washington, D.C. 20005
1-800-2-HELP-90

A Resource and Environmental Profile Analysis (REPA) is a comprehensive way to look at products and/or packages from raw materials extraction to final disposition. It is an inventory, quantifying energy and resource use, and air, water, and land pollutant discharges. This is not a risk assessment. No scientific system has been established to evaluate the health or environmental impacts of the results. Likewise, the principal public policy conclusion that can be drawn is that packages or products should not be judged on a "win/lose" basis. Instead, the packages or products may best be judged on their own and improvements sought to reduce their total environmental consequences and energy/resource requirements (e.g., via reduction and/or recycling).